THE VALUE ADDED BY MANUFACTURING QUALITY REQUIREMENTS

by

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Abstract

A methodology for assessing the value of manufacturing quality requirements to the final product, QVAL, is presented. The prime objective of this project was to reduce the Manufacturing Quality Requirements (MQR) that the Jet Propulsion Laboratory (JPL) imposes on internal and contracted electronics assembly organizations to the minimum number of requirements of significant value to the product. Supporting this objective were several goals, to:

1. Develop a quantitative definition of value added that maybe used to distinguish between marginally useful and significant MQR.
2. Generate a definition of risk associated with reducing the priority of a MQR from mandatory to a guideline or eliminating the requirement altogether.
3. Develop a relatively generic methodology for determining the value added by an MQR.
4. Implement and evaluate this methodology using JPL Workmanship Standards.

An MQR is said to have enough value to avoid devaluation if the following three statements are true:

1) The MQR is not redundant to another MQR.
2) The MQR is not in conflict with another MQR.
3) The MQR quality of performance was found to be adequate as measured by the ability to satisfy the defined need.

The valuation methodology includes:

1) Key Word Coding of MQRs as part of taxonometric sorting for data base entry and retrieval in addition to analysis
2) Definition of need for an MQR
3) Determination of Quality Weight, a way to emphasize specific characteristics of requirements
4) Conflict and redundancy check, where the MQR is compared to existing requirements
5) Engineering review of referred MQRs, which relies on engineering experience and judgment
6) Determination of risk associated with devaluation of an MQR, a quantitative estimate
7) Computation of a Figure of Merit Score, which may be used to rank or classify MQRs
8) Recommendation for disposition.

The FIRST STEP, Key Word Coding, provides a six field numerical description of the MQR which includes:

1) Information granularity: the level of detail addressed
2) Lifecycle stage of application: when (in the product's life) the requirement applies
3) Rule power: the level of demand made by the requirement such as elective vs. mandatory
4) Purpose: the chief goal and emphasis of the requirement
5) Technology application: the area of science focus
6) Source: federal, military or agency source of requirement.

STEP TWO gives recommendations to the engineer analyst for defining the level of need addressed by the MQR; either a want, obligation, or necessity. STEP THREE provides guidelines to the engineer analyst for assigning a Quality Weight to the MQR. The engineer analyst performs a conflict and redundancy check in STEP FOUR by checking each MQR against all others. A database sort is used for this check. MQRs which are found to be in conflict with or are redundant to other requirements are referred for engineering review in STEP FIVE.

The determination of the risk of devaluing an MQR is determined in STEP SIX. Changing the rule power of an MQR from mandatory to elective is an example of devaluation. A Figure of Merit (FOM) score for the MQR is computed in STEP SEVEN as the product of the Need value, Quality Weight, and the sum of the Key Word Code digits. The FOM may be used to categorize MQRs into value levels or as a threshold screening level. In STEP EIGHT, the engineer analyst gives a recommendation for disposition, typically Retain Modify or Eliminate, based on the Key Word Code and FOM score.

At this time, matching contractor quality system details to JPL quality requirements can require two full time weeks of group supervisor time. Application of the QVAL methodology to quality requirements is expected to greatl y reduce this time. Reduction in the overall number of manufacturing quality requirements to those of substantive value to the end product will significant y reduce the cost of qualit y to JPL and its contractors. The following figure shows how the method fits together.

Objectives

The prime objective of this project was to reduce the Manufacturing Quality Requirements (MQR) that JPL imposes on internal and contracted electronics assembly organizations to the minimum number of requirements of significant value to the product. Main project objectives were to:

1. Develop a quantitative dcfmition of value added that may be used to distinguish between marginally useful and significant MQR.
2. Generate a definition of risk associated with reducing the priority of a MQR from mandatory to a guideline, or eliminating the requ ircmcnt altogether.
3. Develop a relatively generic methodology for determining the value added by an MQR.
4. Implement and evaluate this methodology using JPL Workmanship Standards.

The first objective was met by offering the following definition and by the method itself. Value= The quality of performance measured by the ability to satisfy a defined need. A general definition of value is offered here without claiming to be robust in all possible applications, but rather of immediate utility to MQRs applied to electronics assembly operations.

Value = The quality of performance measured by the ability to satisfy a defined need.

'l-his definition is given with the assumptions that 1) Quality can be designed into a product, thereby adding value to the product, but cannot be inspected into the product, and 2) inspection may not detect all defects. The associated quantitative assessment of value is discussed in the next section. Value may also be defined in terms of the Taguchi Loss Function. Using the value definition given above, value would be decreased as the satisfaction of need is reduced with associated cost. The inverse of the Figure of Merit (h'OM), Step 7, score gives an initial estimate for the Taguchi Loss Function constant.

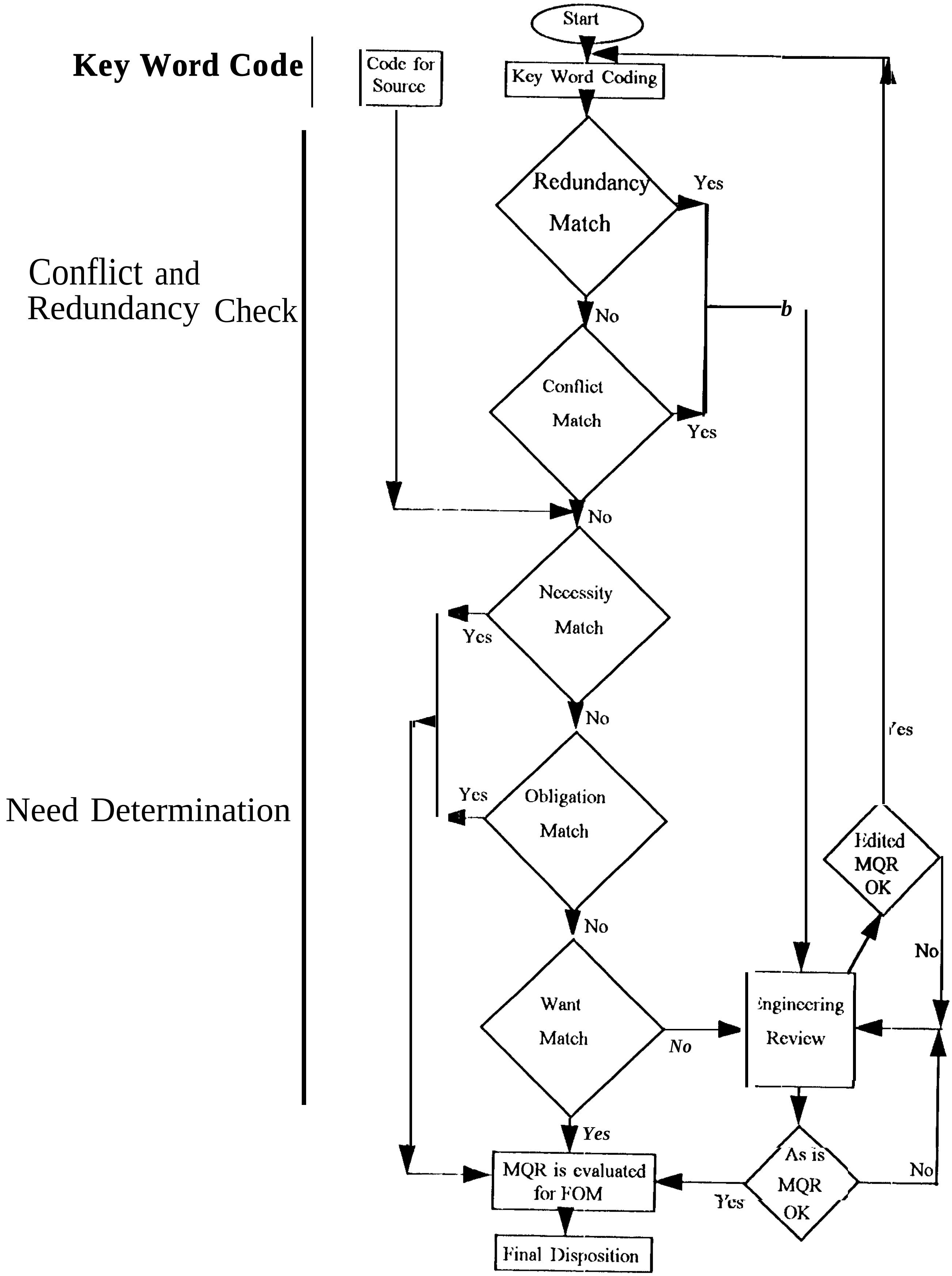


Figure 1. MQR Valuation

Methodology

The Valuation Methodology may bc outlined as follows:

1. Kcy word coding
2. Definition of need
3. Dctcrmination of quality weight
4. Conflict and redundancy check
5. Engineering review of rcfcrrcd MQRs
6. Dctcrmination of risk associated with devaluation of rcfcrrcd MQRs
7. Figure of Merit (FOM) scoring
8, Rccommcndation for disposition

1.0 *Key Word Coding*

Kcy word coding is used to assist database intcgrat ion, for entering MQRs into a database, and as a form of classification for taxonomctric purposes. The coding has no influcncc on MQR valuation other than by helping to identify redundant and conflicting MQRs. The usefulness of the kcy word codes depends on prccisc (rcpcatablc) and accurate MQR coding which is upgraded with MQR revision. A kcy word coding assignment of O indicates that the key code dots not apply to a given MQR. A comma is used as a field (code) delimiter. The "Other" code should rarely bc sclcctcd and should bc further spccificd if sclcctcd. If the "Other" code is sclcctcd routinely, this is an indication that the code designations arc not adequately inclusive and that the QVA1. Kcy Word Coding recommendations need to bc rccvaluatcd.

1. Information granularity: corresponds to product Kit List or As Built List
   1.1 All lcvcls
   1.2 Program
   1.3 Project
   1.4 Systcm
   1.5 Subsystcm
   1.6 Assembly
   1.7 Subassembly
   1.8 Part
   1.9 Other (specify)

2.0 Lifccyclc stage of application: Choose predominant stage if more than onc is involved.
   2.] All lcvcls
   2.2 Concept
   2.3 Design
   2.4 Procurcmcnt
   2.5 Packaging and shipping
   2.6 Validation
      2.6.1 inspection
      2.6.2 Tcst
   2.7 Production process (other than inspection or test)
   2.8 Othcr (specify)

3.0 Rule Power: authority to require that an MQR is followed, i.e. the level of flexibility in applying the MQR.

3.1 Elective
3.2 Recommendation
3.3 Mandate
3.4 Class
3,4.1 Class A: All requirements of a given document
3.4.2 Class B: Level I I requirements of a given document
3.4.2.1 Level II Requirement: project manager signature needed to waive requ i rement
3.4.3 Class C: Level II requirements of given document or other specified documents
3.4.4 Class D: Project option
3.4.4.1 Not a requirement but an option to mitigate technical risk. Project may accept or reject guidelines without a waiver
3.5 Other (specify)

4.0 Purpose; Levels may not be mutually independent, however the MQR should emphasize a particular level.

4.1 Emphasis on more than one level
4.2 Refer to another requirement
4.3 Define words or phrases
4.4 State assumptions
4.5 Exemplify computations
4.6 Specify quant itative tolerance
4.7 Stipulate order or activity
4.8 Specify a given activity
4.9 Other (specify)

5.0 Technology Applicat ion Granularity: requires how a process is to be carried out

5.1 Applies to all technologies
5.2 Granularity is specified in a referral document
5.3 Specific type of equipment
5.3.1 Specific type of material
5,3.1.1 Brand and product identity
5.3.2 Specific type of equipment
5.3.2.1 Brand and model number or other identity
5.3.3 Specific material and equipment
5.4 Not applicable
5.5 Other (specify)

The kcy word code "source" is used for tracking and historical continuity, but is not required for redundancy and/or conflict checking.

6,0 Source
- 6.1 Unknown
- 6.2 Other (Specify)
- 6.3 Commercial
- 6.4 Federal
- 6.5 Military
- 6.6 NASA
- 6.7 JPL

2.0 *Definition of Need*

Value can be measured by performance quality, i.e., the ability to satisfy a need Need can then bc categorized as either a 1) Necessity, 2) Obligation, or 3) Want. A *necessity is* a need that is considered to bc integral to the basic functioning of the system or a critical overall requirement such as safety. Necessity needs arc essential fundamentals that usually do not generate many disparate views, arguments, or demand compromises. ***Obligation*** needs originate from the customer. These needs arc typically only partially questioned, with most requirements accepted as contractual. Needs may also bc categorized as *wants* or requirements which would bc nice to have, but arc not essential. Wants needs often inspire. debate.

Whether the results of an MQR inspection or test is utilized directly impacts the level of need for that MQR. If the results arc not used for downstream decision making or as input to a computation, the MQR is not a necessity for the quality system. Necessity needs may call out tolerances for significant differences between customer goals and actual performance of the component or system. identifying this variance is probably the primary function of most quality systems. To bc considered a necessity need, MQRs must test what was intended using measurable criteria with solid proof that product performance is sensitive to those inspection or test criteria. The match between critical process parameters and the current MQR may also bc an element of necessity needs. Consistency between standards, references, and criteria metrics is very critical to a viable qualit ys ystem and therefore is characterized as a necessity. Another essential need is that MQRs provide information to assist in discriminating among decision alternatives. The lack of any necessity need MQRs substantially undermines the effective application of quality assurance.

The next lower level of need is ***obligation*** need, which should bc directl y mappable to customer requirements. Any MQRs mandated by the customer arc obligation needs. Often these include a rnandatc that quality data bc compatible with the customer's analysis s ystem. Other examples of obligation needs may involve:

- Correlation of lifecycle inspection data to previous process data, i.e., feedback to previous processes
- inspection and test at earliest possible lifecycle stage. By inspecting at the earliest stage possible, defective assemblies may bc separated out before any additional process value can be added
- Diagnosis of process ills in addition to identifying product defects. This requirement must bc fulfilled for continuous process improvement.
- identification of environmental noise, to bc included in Taguchi loss function computations,

The third level of need is *want*. Wants arc needs that would be nice to have, but arc not directly required by the customer and arc not essential for product operation. Although casing manufacturability may be considered essential from some viewpoints, this MQR want is probably not absolutely needed for product function. The quality system evaluation being performed in real time is another attribute which is highly desirable, but not fundamental. Another example of a want type of need is technology flexibility. increasing flexibility will increase process capability indices and possibly widen the range of customer types, but again, is not of primary need for product operation. Want needs can be eliminated without significantly impacting product opcrat ion.

3.0 *Determination of Quality Weight*

The Quality Weight (QWt) assigned should be based on the impact that the requirement is expected to have on the final product quality. Proper Quality Weight assignment depends on experience, the Key Word Code, and engineering judgment. Suggestions for choosing quality weights arc given below.

Key Word Code	Quality Weight . . .
1	All levels have equal impact,
2	All levels have equal impact.
3	If code== 1 then QWt $\leq$ 3 If code= 2,4.2,4.3, or 4.4, then QWt = 7 or 8 If code = 3 or 4.1, then QWt = 9 or 10 The higher the 4.0 Key Code value, the higher the QWt. Requirements showing the greatest impact on product quality would bc given the 3 designation with the appropriate material and/or equipment granularity being specified. It is assumed that if material and/or equipment is specified, this supports optimal quality for that particular product. If the material and/or equipment arc not specified and arc therefore assumed to bc generic, this is less specific to the product and assumed to be less important to product quality. If the MQR applies to all technologies and therefore is not specific to the product, its impact on quality will bc marginal. Thus, If code= 1,2 or 4 then QWt $\leq$ 3 If code= 3 then QWt = 9 or 10. If code= 5 then 4 $\leq$ QWt $\leq$ 8 as specified by "Other"
6	All levels have equal impact,

The following matrix summarizes these rccommcndations, with the row headings showing the Code 3 choices and the column headings representing the Code 5 choices. Cell contents give the suggested Quality Weight assignment. For example, when Code 3 is 4.1 and Code 5 is 3, the recommended Quality Weight is in the range of eight to ten. The Quality Weight should bc selected using more information than just the Code 3 and 5 values.

		Code 5				
		5.1	5.2	5.3	5.4	5.5
	3.1	≤ 3	< 3	4-8	4-8	4-8
	3.2	4	4	4-8	4-8	4-8
Code 3	3.3	8-10	8-10	8-10	8-10	8-10
	3.4.1	8-10	8-10	8-10	8-10	8-10
	3.4.2	≤ 5	≤ 5	4-8	≤ 3	≤ 3
	3.4.3	≤ 5	≤ 5	4-8	≤ 3	≤ 3
	3.4.4	≤ 3	4-7	4-7	≤ 3	≤ 3

4.0 *Conflict and Redundancy Check*

Thc samc one-time check can catch redundancy and/or conflict problems. Conflicts or redundancy may bc indicated by the complctc match of two kcy word codcs. In some cases, MQRs will match in all kcy word codes, but specify different referral documents, which may lead to a conflict. The conflict would then bc assessed during an Engineering Review. The match is performed using a database sort.

R<u>edundant</u> is used hereto indicate a duplicated rcquircmcnt and thcreforc an unnecessary MQR. MQRs arc first compared for redundancy or conflict. Once the kcy code is found to match, the rule power of the two MQRs is compared. An cnginccr will then review the two matching MQRs. In some cases, MQRs will match in all kcy word codes except Rule Power. This is onc example of possibly conflicting MQRs which will require an cnginccring decision,

5.0 *Engineering Review*

Engineering review of rcfcrrcd MQRs relics primarily on cnginccring cxpcricncc and judgment. After the computation of the Quality Weight, the cnginccr dctcrmincs whether the MQR will need furthcr assessment, i.e., is:

- Redundant
- In conflict with another MQR
- Referring to another rcquircmcnt which is no longer valid
- Technologically obsolete
- Too vague to bc useful
- Confusing

The cnginccr rcvicwcr also addresses any other rewording issues.

6.0 *Determination of Devaluation Risk*

The definition and application ofthc risk determination is a continuation of thc Engineering Review step. in the second report wc discussed the assumption that the Baycsian consumer's risk, β' or (Type II error), correlates to the risk associated with accepting product that contains more than a designated lcvcl of defects. Suppose the set of outcomes of an cxpcrimcnt arc defined to bc set B and event A is onc of the outcomes in set B. Baycs' formula is:

$$P(B \mid A) = \frac{P(B \cap A)}{P(A)},$$

meaning the probability y of all of the outcomes in set B happening, given that event *A* is known to have already occurred, is equal to the probability of the events in the intersection of set B and event *A* occurring, divided by the probability of event *A* occurring alone. Bayes' formula takes into account a known level of probability to which questionable event occurrence probabilities are compared. The traditional consumer's risk, β, corr elates to the risk of accepting bad product with no level of defect being specified.

A numerical example of the use of Bayes' theorem in estimating the risk associated with a Type II error (consumer's risk or the risk of accepting bad product) is given below. From the QVAL perspective, this example shows how to estimate the risk associated with accepting bad product because a particular quality specification has had its rule power reduced.

Example

From past experience with similar PCB assembly designs, a probability equivalent to one in 1,000 PCBs has one open when received in test, regardless of which firm manufactured the card. The test is such that when a card actually has one open, a positive result will occur 99% of the time, while a false positive occurs only 2% of the time. If a randomly selected card is tested and the result is positive for an open, what is the probably that the card actually has an open?

Let Al = {card actually has an open}, A_2 = {card does not have an open}, and B = {positive test result }. There arc two ways to receive a positive test result, P(B): 1) Actual open $P(A_1)$, or 2) False positive which can be restated as the chances of a positive test result given that the card does not have an open, $P(B|A_2)$. Al is a given known of 0.001, which implies that the chance of not having an open, A_2 is 1 -0.001 = 0.999. We know that a positive result will occur 99% of the time when an open is actually present, in other words, $P(B|A_1) = 0.99$. False positive results arc known to happen 2% of the time, so $P(B|A_2) = 0.02$.

The probability of having an open and a getting a positive testis then:

$$P(A_1) \text{ and } P(B) = P(A_1 \cap B) = 0.001 \text{ X } 0.99 = 0.00099.$$

The probability of not having an open and a getting a positive test is

$$P(A_2) \text{ and } P(B) = P(A_2 \cap B) = 0.999 \text{X } 0.02 == 0.01998.$$

Thus, the chances of receiving a positive result is the sum:

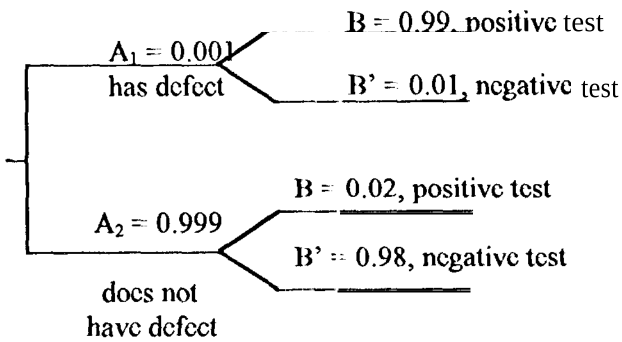
$$P(B) = P(A_1 \cap B) \text{ -t } P(A_2 \cap B) = 0.00099 + 0.1998 = 0.02097$$

Applying Bayes' theorem to answer the original question, "If the test is positive, what arc the chances that the tested card actual] y has an open?":

$$P(A_1|B) = \frac{P(A_1 \cap B)}{P(B)} = \frac{0.>00099}{0.02097} = 0.047$$

This result seems to be counter-intuitive; the diagnostic test appears to be so accurate that we expect a card with a positive test for an open to be highly likely to actually have an open, whereas the computed conditional probability is only 0.047. Because the open defect is rare and the test only moderatel y reliable, most positive test results arise from errors rather than from actual opens. The probability of having an open has increased by a multiplicative factor of 47 (from prior 0.001 to posterior 0.047). To further increase the posterior probability a diagnostic test with a much smaller error rates is needed. If the defect were not so rare (for example, a 25°/0 incidence among all cards), then the error rate for the present test would provide good diagnoses.

Although 100’% sampling is the policy for test and inspection at JPL, with only four or five cards making up the population, estimating defect rates can be difficult. Risk assessment difficulty is also increased by the fact that opens or other defects are usually very rare due to high reliability processing. The method demonstrated above will give a risk assessment as accurate as the estimates of defect rates and test accuracy used to compute the risk. The following tree diagram shows the probabilities used in the example.



7.0 *Figure of Merit Scoring*

Figure of Merit Scoring is derived from the product of the Key Word Total, the Need value, and the Quality Weight. The FOM score maybe used for further database sorting, whether or not the requirement underwent engineering review, all MQRs are given a Figure of Merit score, the Seventh Step and quantitative assessment of the value adding potential of an MQR. In general, the lower the FOM score, the lower the value added to the final product by the requirement. However, there is no straight-forward (linear) relationship between the FOM and the Disposition. Engineering judgment must be called on to evaluate the MQR Disposition, the last and Eighth Step, given the Key Word Code, Need Determination and FOM. The following figure shows the overall database structure for the QVAL analysis.

8.0 *Dispositioning*

The last and eighth method step is the recommendation for disposition which is a subjective call based on engineering judgment. Any “Modify” Dispositions which completely match ***other*** requirement Key Codes and Need Definitions are examined further by review engineers. The engineer should heed the guidance offered by the Key Word Coding and the FOM score values. The following figures show the QVAL method flow.

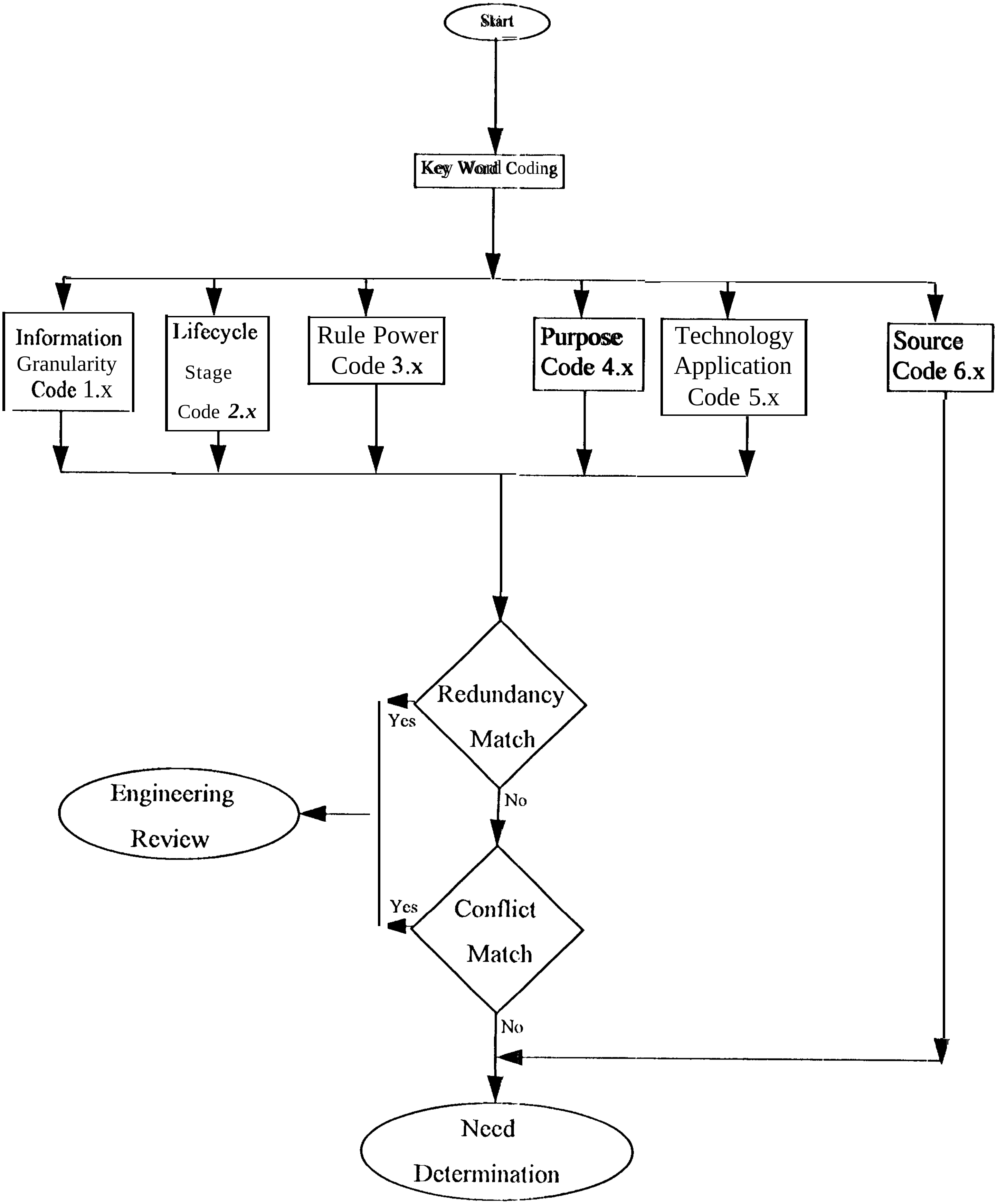


Figure 2. MQR Conflict and Redundancy Check

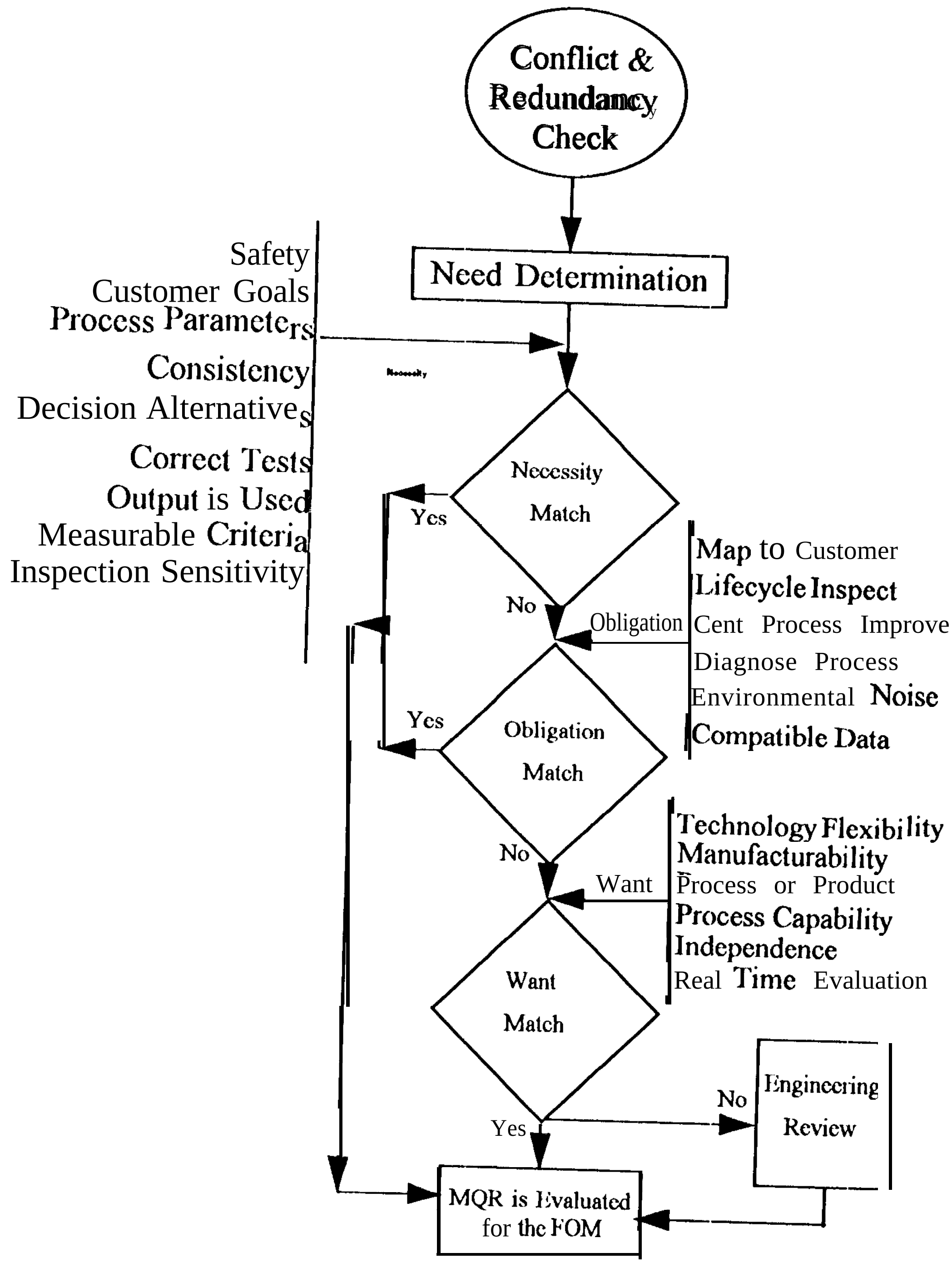


Figure 3. MQR Need Determination

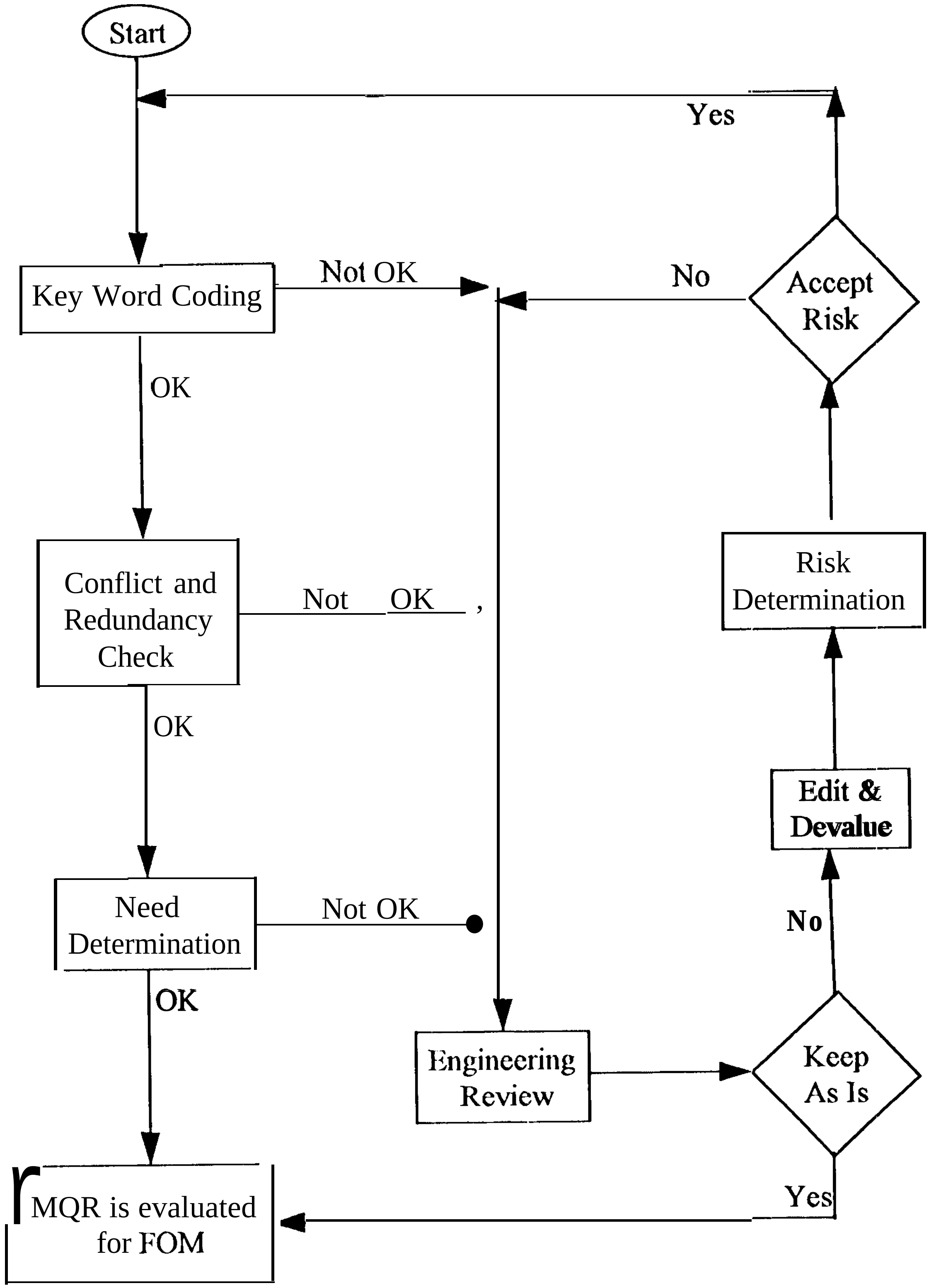


Figure 4. MQR Engineering Review